THE EMERGING NANO-CORPORATE PARADIGM: NANOTECHNOLOGY AND THE TRANSFORMATION OF NATURE, FOOD AND AGRI-FOOD SYSTEMS[*]

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Introduction

Nanotechnology is emerging as the technological platform for the next wave of development and transformation of agri-food systems. Nanotechnology is attracting large-scale investment from global food corporations, is backed by academic science, and has captured financial and ideological support from many governments around the world (see for example Roco, 2005; Sandler and Kay, 2006). As a result, nanotechnology is rapidly moving from the laboratory and onto the farm, supermarket shelves and the kitchen table. For example, a new range of 'smart' agricultural inputs and products are being developed, such as nano-seed varieties with in-built pesticides that will release under certain environmental conditions; nano-encapsulation techniques may make it possible to alter the nutritional composition, flavour and other attributes of food to match consumers' personal tastes and physiological requirements; and 'smart' food packaging able to detect the presence of pathogens. These and other applications of nanotechnology across the agri-food system are emerging from a growing alliance between the corporate food sector and scientific communities (see for example Helmut Keiser, 2004; Joseph and Morrison, 2006). This industrial and scientific collaboration strategically place the corporate sector to shape the research trajectory and commercial applications of nanotechnology, and the future of agri-food systems.

This paper provides an overview of some of the growing number of nano-applications being researched and commercialised across the agriculture and food sectors. This includes considering the ways in which the techniques and products of nanotechnology may extend, entrench and exacerbate, but also reconstitute or transform the social and ecological relations that they mediate. We will refer to the emergence of a 'nano-corporate food paradigm' as a way of identifying some of the technical, ecological, and socio-economic characteristics associated with the incorporation of the techniques and products of nanotechnology across the food system. For example, in terms of ecological relations, nanotechnology represents the most powerful set of techniques yet developed to take apart and reconstitute nature at the atomic level. In terms of economic relations, nanotechnology provides new opportunities for the extension and further integration of corporate ownership and control within and between sectors of the agri-food system. We will also reflect on the relationship between this nano-corporate paradigm and other recent techno-economic paradigms of agri-food production and consumption.

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Nanotechnology Defined: Techniques, Risks and Regulation

Nanotechnology commonly refers to any engineered materials, structures and systems that operate at a scale of 100 nanometres or less (one nanometre is one billionth of a metre) (Moraru et al., 2003). Nanotechnology is essentially a set of techniques that enable the direct manipulation and reconstruction of the world at the level of atoms and molecules. Nanotechnology introduces the most powerful set of tools to date which enable scientists to deconstitute or decompose nature into its constituent components — atoms, molecules and super-molecular structures — and to reconstitute and recombine these components into new forms (Scrinis, 2006a).

There are a diverse range of existing and promised techniques, devices and applications that come under the broad banner of nanotechnology. Nanotechnology is not so much a separate and distinct technological field, but rather a new techno-scientific platform, whereby a range of existing techno-scientific disciplines — such as chemistry, physics, biology, biotechnology, neurology, information technology and engineering — are able to shift down to the molecular level (ETC Group, 2003; Hunt and Mehta, 2006). Nanotechnology will facilitate the accelerated development of these various techno-sciences, including the development of nano-chemical technologies, nano-biotechnologies and nano-information technologies (Shand and Wetter, 2006). Nanotechnology will also enable a greater degree of integration and convergence across the various techno-scientific disciplines, technologies, and technological products. A number of types of nano-techniques and applications can be distinguished, including the manufacture of nanoparticles, nanofabrication techniques, and the field of nano-biotechnology (ETC Group, 2003).

Nanoparticle production includes the breaking down of larger-scale chemical compounds and materials into nano-scale particles — referred to as the ‘top-down’ approach to nanotechnology — as well as the manufacture of distinctly new materials, such as carbon nanotubes, buckyballs and quantum dots. Simply dealing with materials at the nanoscale can change their properties in comparison with the same materials at a larger scale. This is in part because smaller particle sizes increase the surface area of molecules. The nanoscale material could be more reactive, have different optical, magnetic and electric properties, and may be stronger or more toxic (Royal Society and Royal Academy of Engineering, 2004).

In addition to the manufacture of nanoparticles, there are also nanotechnologies being developed for assembling materials and products at the atomic and molecular level from the ‘bottom-up’, atom-by-atom or molecule-by-molecule (Royal Society and Royal Academy of Engineering, 2004). The approaches to bottom-up manufacturing include chemical synthesis, self-assembly and positional assembly techniques. For example, molecular self-assembly involves the use of supramolecular chemistry to cause molecules to self-assemble into a particular configuration. DNA nanotechnology refers to techniques for constructing molecular structures out of DNA (Patrick McCray, 2005; ETC Group 2003).

Nanoparticles, nano-devides and other nano-systems may be used to produce cheaper, more durable, or greater quantities of existing commercial products. They can also be used to manufacture products with new or enhanced qualities, such as ‘smart’ surfaces and materials, faster computer chips, pharmaceuticals able to target particular organs in the body, and ultra-small sensors and monitoring devices that can be utilised across a range of industries (ETC Group, 2003).

Nano-biotechnology refers to the use of nanotechnology to manipulate living organisms, as well as to enable the merging of biological and non-biological materials. This includes the use of nanotechnology to facilitate genetic engineering breeding programs, the incorporation of synthetic materials into biological organisms, and ultimately the creation of new life forms. The ETC Group refer to the creation of new life forms through the development of 'synthetic biology' as one of the ultimate goals of nano-biotechnology research (ETC Group, 2007). Synthetic biology entails going beyond merely cutting and pasting existing gene sequences between organisms — and the current imprecision, randomness and other limitations of these techniques — and instead involves constructing DNA itself out of atomic building blocks, with the aim of creating novel organisms that are able to be 'programmed' to more precise specifications. Rodney Brooks from the Massachussetts Institute of Technology puts forward this vision of a nano-biotech future: "Much of what we manufacture now will be grown in the future, through the use of genetically engineered organisms that carry out molecular manipulation under our digital control. Our bodies and the material in our factories will be the same…we will begin to see ourselves as simply a part of the infrastructure of industry" (ETC Group, 2005b: 13).

In these ways, atomic elements and molecular structures become the Lego-style building blocks for producing a wide range of materials and products across all industrial sectors. Nanotechnology extends the *reconstitutive rationality* that has characterised the contemporary techno-sciences, and which can be defined as where the objects of nature are not merely used and exploited in their received form, but increasingly encountered as malleable and available for reconstruction from the ground up — or in this case, from the atom up.[1] Nanotechnology can also be understood as constituting a materially *more abstract* level, or mode, of engagement with nature — a way of taking hold of and transforming nature that is further abstracted from the objects of everyday sensible and practical experience (Sharp, 1992).

Nanotechnology research and development is being undertaken by most of the world's largest corporations, as well as by university research centres and smaller start-up companies. The intensive patenting of nano-scale techniques and materials is a key feature of the nanotech industry, with many competing and overlapping claims threatening to lead to costly legal disputes (ETC Group, 2005b; Shand and Wetter, 2006). Given the materially fundamental nature of these patents and their widespread applicability across applications and industries, the control of these broad nano-patents may be a strategy for corporate concentration both within and across industrial sectors.

The novel characteristics of nanoparticles and other nanomaterials that offer new and desirable traits for a range of industrial applications may also be the source of new forms of hazards to environments and people, such as new forms of toxicity and new forms of pollution (Colvin, 2003; Tolstoshev, 2006; ETC Group, 2004; Scrinis, 2006a). There is little known about the health affects of eating foods that contain nano-particles, or of workers handling nano-materials. A report by the British Royal Society has warned of the serious risks of nano-toxicity (Royal Society and Royal Academy of Engineering, 2004). The International Union of Food, Farm and Hotel Workers (IUF) have called for a moratorium on nanotechnology until the effects of exposure to nano-materials is more thoroughly understood (International Union of Food, Farm and Hotel Workers, 2007). A key concern regarding human exposure to nano-scale particles is that they have many pathways for entering the body, such as through inhalation, digestion and through the skin. From there they may be able to pass into the bloodstream, penetrate cells, by-pass immune responses, lodge in the lungs, and cross the blood-brain barrier (Friends of the Earth, 2006; Royal Society and Royal Academy of Engineering, 2004; Scrinis 2006b). The similarity in size of some nanoparticles

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[1] This 'reconstitutive' form of rationality can be understood as over-laying and framing the formerly dominant 'instrumental' form of rationality, the latter characterised by the use and exploitation of nature or natural objects in their received form.

with asbestos has often been noted (see for example Swiss Re, 2004). Many commentators have also drawn parallels between genetically modified foods and nano-foods in terms of the types of risks they introduce, as well as in terms of the inadequacy of the testing and regulatory frameworks governing these technologies (see for example Bowman and Hodge, 2006: Bowman and Fitzharris, 2007).

Civil society groups and non-government organizations — notably the ETC Group and Friends of the Earth Australia — have been calling for a moratorium on the release of any products of nanotechnology until adequate regulatory frameworks are in place; until the public are democratically involved in decision making over the applications and broad societal consequences of these technological innovations; and until such products are shown to be safe (Bowman and Hodge, 2006; ETC Group, 2005c; Friends of the Earth, 2007). To date, there have been very limited opportunities for public engagement in nanotechnology debates (Bowman and Hodge, 2006; 2007). Yet a recent report by the Woodrow Wilson Center for International Scholars' Project on Emerging Nanotechnologies concluded; "involvement of members of the general public is crucial for dealing with nanotechnology's adverse effects . . . the public needs to be involved in assessing nanotechnology's risks, as well as in defining the measures to be taken to deal with the risks" (Davies, 2006: 29).

Despite these risks, and the current limits of public engagement in debates about nanotechnology, nanotech materials and products are being researched and commercialised by scientists and companies across all sectors of the agri-food system. Applications include farming technologies and inputs, food processing, food packaging and retailing. Reflecting the extent of nano research, development and commercialisation, by 2004 the market for nanotech food and food processing was estimated to be worth US$2 billion. This figure is set to expand to US$20 billion by 2010 if current trends continue (Kuzma and VerHage, 2006).

Proponents of nano-food applications argue that they offer the capacity to bring on-going improvements to agriculture and food systems: they argue it will improve the productivity and efficiency of crop and livestock production, as well as increasing the safety, nutritional value, and shelf-life of food, and helping to increase food production to meet future population growth trends (Joseph and Morrison, 2006; Rutzke, 2003). This paper will now identify and evaluate some of the specific applications and implications of nanotechnology within the various sectors of the agri-food system.

Nano-Agricultural Applications

In the agricultural sector, nanotech research and development is likely to facilitate and frame the next stage of development of genetically modified crops, animal production inputs, chemical pesticides and precision farming techniques. While nano-chemical pesticides are already in use, other applications are still in their early stages, and it may be many years before they are commercialised. These applications are largely intended to address some of the limitations and challenges facing large-scale, chemical and capital intensive farming systems. This includes the fine-tuning and more precise micro-management of soils; the more efficient and targeted use of inputs; new toxin formulations for pest control; new crop and animal traits; and the diversification and differentiation of farming practices and products within the context of large-scale and highly uniform systems of production.

Through the convergence of nano and bio techniques, it may be possible to improve the precision of genetic engineering breeding programs, thereby ensuring greater control in delivering new character traits to plant and crop varieties (ETC Group, 2004). Researchers are attempting to use nanoparticles, nanofibres and nanocapsules to introduce foreign DNA and chemicals into cells (Friends of the Earth, 2008 forthcoming). For example, silica nanoparticles have been used to deliver DNA and chemicals into plant and animal cells and tissues (Torney, 2007). Researchers in this field have also already succeeded in "drilling" holes through the membrane of rice cells to enable the insertion of a nitrogen atom, to stimulate rearrangement of the rice DNA (ETC Group, 2004). This technique has been successful in altering the colour of rice, and researchers aim to use this technique to extend the growing season for rice, enabling year round production. There is, however, little evidence of any commercial applications of such nano-genetic engineering research at this stage.

The perhaps more distant prospect of not merely re-engineering existing plants, but of creating novel plant varieties from scratch using synthetic biology would enable significantly greater control over crop traits (ETC Group, 2007). While such developments may be a number of years away, Drew Endy, an engineer and promoter of synthetic biology has claimed: "There is no technical barrier to synthesizing plants and animals, it will happen as soon as anyone pays for it" (ETC Group, 2007: 23).

Techniques at the nano-scale are also being applied in an attempt to enable the targeted delivery or increased toxicity of pesticide applications (ETC Group, 2004; Kuzma and VerHage, 2006). This includes the insertion of nano-scale active ingredients into pesticides. The specific properties of these nano-scale materials, such as their ability to dissolve in water or their increased stability, are designed to maximise the effectiveness of these pesticides. Leading agri-chemical companies including BASF, Bayer Crop Science, Monsanto and Syngenta are engaged in nanotech research in these areas. In terms of commercial applications of this technology, Syngenta, the world's largest agrochemical company, currently retail a number of chemicals with emulsions that contain nanoparticles. Agrochemicals include 'Primo MAXX Plant Growth Regulator', 'Banner MAXX Fungicide', 'ApronMaxx RFC seed treatment' and 'Cruise Maxx Beans' (ETC Group, 2004; Friends of the Earth, 2008 forthcoming). To date, none of these agrochemicals are currently labelled as containing nanoparticles.

Pesticides may also be encapsulated via nano-encapsulation techniques. These encapsulation techniques enable greater control over the circumstances in which encapsulated pesticides will be released. For example, pesticides could be released quickly or slowly – depending on need – and under specific conditions, such as moisture and heat levels (see for example Syngenta, 2007; Zhang et al., 2006). Syngenta have obtained a patent for a 'gutbuster' microcapsule containing pesticides that will break open in alkaline environments, including the stomach of certain insects (ETC Group, 2004). Such nano-encapsulation techniques not only provide in-built pesticides for crops – in some ways similar to genetically modified *Bt* insecticidal crops – but also in-built switches to control the release and subsequent availability of pesticides.

One of the rationales for these nano-particle pesticide applications lies in their improved capacity for absorption into plants compared to larger particles. As such, they may not be washed off as readily, thereby increasing their effectiveness, but also posing a new order of risks to consumers of these products (see for example Belfield, 2005). Farm workers and rural residents are also being exposed to these nano-pesticides, in the absence of any required safety testing or regulation of nano-scale formulations of already approved chemical pesticides (Lyons and Scrinis, 2008 forthcoming). The size and dissolvability of nanoparticle pesticides may also mean they contaminate soils, waterways and foodchains across a wider geographical area, while nano-encapsulated pesticides may release their toxins in other environments or in the stomachs of other living organisms.

Nano-pesticide research and development is concentrated within a small number of large agri-chemical companies that already dominate the agri-chemical and seed market, and these corporate actors are likely to further extend their control of these markets, and therefore over farmers (Lyons, 2006; Friends of the Earth, 2008 forthcoming). Proponents argue that pesticidal applications of nanotechnology promise to reduce pesticide use, due to their more precise and targeted nature. As such, nanotechnology is frequently portrayed as introducing environmental benefits (see for example Dept of Environment, Food and Rural Affairs, 2007). However, as in the case of GM crops, these efficiency gains may also provide ideological legitimation for, and thereby further entrench, chemically-intensive farming systems. The reformulation of the active ingredients of patented pesticides into nano-scale formulations may also be used as a strategy for agri-chemical corporations to apply for an extension of their patent rights after the initial patent period has expired (Friends of the Earth, 2008 forthcoming).

Nanosensors — or nano-scale, wireless sensors — represent the intersection of nanotechnologies and information technologies. Alongside geographical positioning systems and other information technologies, nanosensors could be scattered across farmers' fields to enable the 'real time' monitoring of crops and soils, and the early detection of potential problems, such as pest attacks and declining soil nutrient levels (ETC Group, 2004). Nanosensors have the capacity to extend the logic of precision farming in new and novel ways – to both identify and rectify agronomic problems in a very short time frame. The US Department of Agriculture, for example, is reported to be developing a "Smart Field System" that "automatically detects, locates, reports and applies water, fertilisers and pesticides — going beyond sensing to automatic application" (ETC Group, 2004: 17). Nanosensors may thereby introduce greater efficiencies within — and thereby facilitate the expansion of — large scale farming operations.

Nanotechnology also has the potential to displace traditional food and non-food farm commodities through the development of artificial nanomaterials in factories (ETC Group, 2004; 2005a). It is the farming communities and countries of the South that produce some of these commodities, such as cotton and rubber, which would be most severely affected by these crop substitutions. For example, the global cotton market and cotton prices could be further undermined by the development of synthetic fibres such as Nano-Tex, which is reported to be a much stronger material than cotton but with a similar texture. Similarly, nanoparticle alternatives to rubber are already in production, such as silica carbine nanoparticles and carbon nanotubes for use in car tyres. Another more distant possibility is that crops could be engineered to themselves produce nanoparticles, referred to by the ETC Group as "particle farming", whereby plants are used to extract particular minerals from the soil for harvesting (ETC Group, 2004: 27).

Nanotechnology also has a range of potential applications for animal production systems, including new tools to aid animal breeding, targeted disease treatment delivery systems, new materials for pathogen detection, and identity preservation systems (Scott, 2007; Ajmone Marsan et. al., 2007; ETC Group, 2004). Examples include the use of micro and nanofluidics systems for the mass production of embryos for breeding; drug delivery systems able to penetrate previously inaccessible parts of the body; more biologically active drug compounds; and sensors for monitoring livestock locations. For fish farming operations, nano-applications include nano-scale water cleaning products, and nanocapsule vaccines released into fishponds which are absorbed into the cells of the fish and then activated using ultrasound (ETC Group, 2004). These nanotech animal and fish production technologies are essentially ways of creating efficiencies and productivity gains within capital and input intensive industrial production operations, including close confinement factory production.

They largely involve re-engineering and further adapting animals to the requirements of this mode of animal production. As the ETC Group put it, “retrofitting farm animals with sensors, drug chips and nano-capsules will further extend the vision of animals as industrial production units” (ETC Group, 2004: 34).

The economic impacts of nanotech developments are likely to affect farmers differentially, depending on the size and capital-intensity of the production unit. As with earlier technological innovations, it is larger-scale, capital-intensive farming operations that will be more able to reap any early economic advantages from adopting nano-applications. Farming communities in the South, particularly smaller-scale and local market and subsistence oriented farmers, as well as agricultural labourers, may be adversely affected in a number of ways. This includes the continuation of commodity price depression through any productivity increases and dumping of produce in the South; the displacement or undermining of traditional agricultural commodities through the development of nanotechnological industrial alternatives; and the reduction in farm labour through the increased efficiency, mechanisation or automation of farming practices (ETC Group, 2004; 2005b.

Nano-Processed Foods

Nanotechnology is also being applied to the production of processed foods and drinks, and a number of foods containing nanoparticles and nanocapsules are currently available for purchase, though without being required to indicate the presence of these nano-materials on their packaging. These nano-processed foods have entered the food supply largely in the absence of public awareness, nano-specific labelling requirements, or nano-specific food safety regulations. Most major food companies, including HJ Heinz, Nestle, Hershey Foods and Unilever, have invested heavily in nanotech research and development in these areas. Kraft’s global ‘Nanotek Research Consortium’ of 15 universities and national research laboratories, for example, reflects a corporate strategy to lead developments for a nano food future (Kuzma and VerHage, 2006).

As Peerak Sanguansri and Mary Ann Augustin describe this shift in scale in food science and technology research; “The next wave of food innovation will…require a shift of focus from macroscopic properties to those on the meso- and nano-scales, as these subsequently control the hierarchical structures in food and food functionality” (Sanguarnsri and Augustin, 2006: 547). A range of nano techniques and materials are being developed in an attempt to assert greater control over food character traits, and to enhance processing functionalities, such as flavour, texture, speed of processing, heat tolerance, shelf life, and the bioavailability of nutrients (Gardener, 2002). As with all food processing research and development, one of the aims is to achieve these ends in a cost effective way, and to continue producing cheap convenience foods with consumer appeal. But a major growth area has also been in the development of so-called ‘functional foods’ — nutritionally engineered foods that are marketed with nutrient or health claims (Scrinis, 2008b forthcoming) — and nanotechnology provides a range of approaches to the cost effective production of foods with modified nutrient profiles and novel traits .

Nanotechnology applications include a range of nano-scale materials added to foods and nano-encapsulation techniques as delivery systems for other food components (Nichols, 2007). Nanoparticle-sized ingredients may increase the functionality or bioavailability of ingredients and nutrients, and thereby minimise the concentrations needed in the food product (Weiss et al., 2006). Food companies are currently producing nanoparticles in emulsions in an attempt to control the material properties of foodstuffs, such as in the manufacture of ice cream to increase texture uniformity (Rowan, 2004). Encapsulation techniques are also being applied as part of a strategy to harness the controlled delivery of nutrients and other components in processed foods. For example, many of the Omega 3 additives commonly found in food are of both nano and micro-encapsulated size.

Food industries argue the addition of micro and nanocapsules to processed foods will improve both the availability and delivery of nutrients, thereby enhancing a food's nutritional status (Kuzma and VerHage, 2006). For example, a recent study claimed that the encapsulation in nanoemulsions of curcumin — the phytochemical found in tumeric and claimed to have antitumor and anticarcinogenic properties — increased the bioavailability of this compound (Wang, 2007). Nanotechnology also holds out the promise of 'interactive' foods able to change their nutritional profile in response to an individual's allergies, dietary needs or food preferences (FOE, 2008 forthcoming). This promise of "personalised nutrition" — based on the development of targeted delivery systems — is described in the food industry journal *Food Technology* by Chen *et al*:

> …advances in nanotechnology may lead to multifunctional nanoscale nutraceutical delivery systems that can simultaneously detect and recognise the appropriate location, analyze the local and global needs, decide whether or how much of the payload should be released, and monitor the response for feedback" (Chen et al., 2006: 36).

The proliferation of such nutritionally-engineered foods — along with some novel nutrient traits and interactive functions — will further promote and accentuate the nutritionally reductive approach to food that now dominates public discourses on the relationship between food and bodily health. This ideology or paradigm of "nutritionism" is associated with an increasingly "functional approach to food and the body", whereby foods are conceived in terms of their functional components and their impacts on specific bodily processes (Scrinis, 2002; 2008a forthcoming). This way of understanding and engaging with food renders consumers ever more susceptible to the nutrient-content claims and health claims used to promote processed foods, and also facilitates the further commodification of food knowledge and preparation skills and their embedding in value-added products.

The introduction of nano-scale components in foods also raises novel health concerns. For example, as Arpad Pustzai and Susan Bardocz note in their review of the health risks of nanoscale food components, nanoparticle versions of the food additives titanium oxide and silicon dioxide are already being used in foods, and have been approved as GRAS (generally recognised as safe) by the US Food and Drug Administration. Yet they argue that there is already sufficient scientific evidence that these nanoparticles are cytotoxic (i.e. toxic to cells), and that they have been incorporated into foods without appropriate safety testing (Pustzai and Bardocz, 2006).

Nano-Food Packaging and Other Applications

To date, the nano food packaging sector has experienced some of the most significant developments in terms of commercialisation (see for example Helmut Keiser, 2004; Joseph and Morrison, 2006). Manufacturers are applying nano techniques with the aim of improving the quality, durability and shelf life of packaged foods. At the same time, they may provide food industries with a new platform to define and regulate the terms of food safety. Nano packaging applications are anticipated to grow from a $66 million business in 2003, to over $360 million by 2008 (Brody, 2006). These various packaging applications may facilitate an expansion in the type of foods packaged, their durability, and the distances they may be transported, thereby facilitating an expansion in the national and global distribution of foods. While promising to deliver 'safer', pathogen-free food, the production of 'smart' packaging may also undermine individuals' knowledge and skills in determining the freshness and safety of food (Friends of the Earth, 2008 forthcoming).

A new range of so-called 'smart packaging' is being developed through the application of nano-sensors able to detect the release of particular chemicals. The packaging may be engineered to change colour to warn the consumer if a food is beginning to spoil, or has been contaminated by pathogens. To do this, electronic 'noses' and 'tongues' will be designed to mimic human sensory capacities, enabling them to 'taste' or 'smell' scents and flavours (ETC Group, 2004).

Nano techniques are also being applied to improve food quality attributes, including the shelf life and freshness of food. For example, nano-composite barrier technology is being used to strengthen a range of packaging materials. The aim is to strengthen the barrier between carbon dioxide and oxygen, thereby keeping food fresher longer — or at least slowing down the rotting process — while at the same time blocking packaging materials from absorbing flavour or vitamin content (Rowan, 2004). Nanocor is a leading manufacturer of nano-composite plastics, and currently hold more than 40 patents for these nano techniques. Miller Brewing has also used nano-composite barrier technology to create plastic beer bottles they claim are stronger than their glass counterparts, while nano-particles provide a strong barrier to increase the shelf life of the beer (ETC Group, 2004).

Nanotechniques are also being used to develop food identifiers that may be able to detect contaminants in food and animal feed. The aim is to increase the security of manufacturing, processing, and the shipment of food, by enabling early detection of contaminants, and the removal of infected products from the food chain. In this vein, bioMerieux have developed a multi-detection test – FoodExpertID. This test enables detection of vertebrates in animal feed, and thus represents a nano surveillance response to food scares, including outbreaks of Mad Cow Disease (CJD) arising from the contamination of animal feed with animal products (bioMerieux, 2004).

A new range of nano-barcodes and monitoring devices are also being developed. This includes nano-scale radio frequency identification tags (RFid) able to track containers or individual food items. These RFid tags could also transmit information after a product leaves the supermarket, unless the tags are disabled at the check-out register (ETC Group, 2004). The nanotech company pSiNutria are also developing nano-based tracking technologies, including an ingestible BioSilicon which could be placed in foods for monitoring purposes, but could also be eaten by consumers (Friends of the Earth, 2008 forthcoming). Supermarkets would use nanosensors to monitor product sales and expiry dates, enabling them to reduce their response time for product re-ordering (Kuzma and VerHage, 2006). Nano-sensors may thereby further increase the efficiency of management and buying arrangements for the large-scale retailers able to absorb the costs of these nano-monitoring and identification techniques.

For home kitchens, a number of companies – including LG Electricals, Samsung and Daewoo – have designed 'smart fridges'. The so-called 'intelligence' of these fridges is attributed to the addition of silver nanoparticles, which are intended to inhibit bacterial growth and eliminate odours in fridges. While nano-silver fridges are marketed as a technology to improve food safety, civil society groups and others have drawn attention to the potential toxicity of nano-silver materials in their products (Foladori and Invernizzi, 2007; Royal Society and Royal Academy of Engineering, 2004).

The Nano-Corporate Food Paradigm

This array of nano-applications – from the farm to the kitchen – demonstrate the extent to which nanotechnology is already being integrated throughout agri-food systems. The scale of corporate investment in nanotechnology suggests that it is likely we will see significant and on-going expansion in nanotechnologies across agri-food systems. In this light, nanotechnology is set to become the dominant techno-scientific form that will frame the next stage of development and transformation of the agri-food system. We will refer to the 'nano-corporate food paradigm' as a way of broadly defining and grouping together some of the likely common features and characteristics of the application of nanotechnology across the agri-food system, and more generally for identifying a distinct techno-economic paradigm of agri-food production, distribution and consumption. While the range of applications of nanotechnology within and between different sectors of the agri-food system will be very diverse, we argue that the nano-corporate food paradigm will be characterised by the continuation, extension, exacerbation as well as transformation of some of the dominant technological, ecological and socio-economic relations within and across the various sectors of the food system.

Technical Characteristics

There are a number of technical characteristics that are likely to frame the development and application of nanotechnologies across the agri-food system. First, the reconstitutive logic of nanotechnology will enable the re-engineering of crops, animals and other living organisms at the genetic and cellular levels, the reconstitution of agricultural inputs, and new techniques for producing a range of 'processed-reconstituted' foods. Atomic and molecular structures, rather than whole organisms and wholefoods, will increasingly become the building blocks and primary inputs in agricultural production and final-food preparation systems (Weiss et al., 2006).

Second, nanotechnology enables the development of more precise, efficient, 'smart' and self-regulating production technologies and inputs. Nanotechnology will enhance the ability to engineer products, tools and systems that are delivered relatively more precisely, or with new, more precisely tailored traits; new production efficiencies designed to reduce inputs and waste; interactive or cybernetic technologies designed to respond to particular conditions or triggers; and the ability to 'stack' a number of traits and features into foods, seeds and other inputs (see for example Savage and Diallo, 2005; Ross et al., 2004).

Third, nanotechnology enables the development of tools and systems for the identification, tracking, monitoring and surveillance of inputs, products and systems, for the purposes of identity preservation, reporting, quality control, and the policing of patent compliance (Hu et al., 2007).

Fourth, the ability to manufacture new types of materials and to modify the traits of crops and food products may mean that both the inputs and end-products of agricultural and food processing systems may be rendered increasingly interchangeable. This includes the ability to develop 'artificial' alternatives to food crops for the food processing industry, or to modify the traits of particular crops to broaden their functional properties. This interchangebility of inputs and outputs would thereby facilitate the extension of existing 'appropriationist' and 'substitutionist' strategies across the food system (Goodman et al., 1987, Goodman & Wilkinson, 1990).

Finally, nanotechnology is a technological platform that provides the technological basis both for the further development of existing techno-scientific forms, and — importantly — for the projected convergence and integration of these technologies. There is also the potential to apply the techniques, materials and products of nanotechnology across a range of applications and sectors of the agri-food system, in much the same way that the new biotechnologies have facilitated the integration of the seed and chemical sectors, and the convergence of the agri-food and pharmaceutical industries though the emergence of 'life science' corporations (Goodman and Wilkinson, 1990; Kloppenburg, 2004). Nano-encapsulation techniques, for example, could be applied both in the encapsulation of pesticides for farm use and the encapsulation of nutrients for processed foods (Friends of the Earth, 2008 forthcoming). In these ways, nanotechnology may give greater unity to otherwise distinct technological trajectories in the contemporary era.

Ecological Relations

These techno-scientific characteristics will in turn constitute or enable the extension and continued transformation of the ecological relations of the contemporary food system. Nanotechnology greatly extends the ability to engage with, transform and reconstitute nature at the atomic and molecular levels, including the engineering of thoroughly novel organisms, materials and final food products. While this level of engagement with nature is not in itself new, its reach and the ability to apply it in a wider range of situations is being radically enhanced. This mode of engagement involves encountering nature — ie. plants, animals, microorganisms, wholefoods — as being constructed from a set of standardised and increasingly interchangeable nano-molecular components (Scrinis, 2006a). There is little respect here for the integrity of the objects of nature in their received form, for all are encountered as plastic and malleable, a standing-reserve of raw material (Heidegger, 1977) ready to provide useful components, to be re-engineered from the atom up, or whose self-assembling properties at the molecular level are to be harnessed, in order to meet the requirements of — and to be smoothly integrated into — the dominant agri-food system (Dupuy, 2007). This more abstract mode of encountering nature will increasingly define the character of food production practices and products as it works its way through the system, including plant and animal breeding and production practices, food processing techniques and products, and consumption practices.

Within the terms of this form of ecological relations, nanotechnology may enable the more *efficient* use of natural resources for many applications and situations. This efficiency may take the form of the reduction in pesticide or fertiliser use, or the development of biodegradable packaging. This technological efficiency has come to define the character of the dominant sustainability discourses within and outside of the agri-food system (Beder, 1997; Lockie, 2001). Genetically modified crops have similarly been promoted on the basis of this more efficient use of agri-inputs, with the aim of legitimating chemical-intensive farming practices (Scrinis, 2007; Buttel, 2007).

This enhanced capacity to reconstitute nature at the nano-scale also introduces novel kinds of hazards and new orders of risk. There may be an inherent unpredictability and unmanageability associated with atomic and molecular level manipulations of nature (Dupuy and Grinbaum, 2006). Despite the enhanced level of precision associated with the nanotechnological manipulation of nature at the atomic and molecular level, there is nevertheless still a considerable lack of precision in understanding and being able to control the consequences of these nano-atomic level manipulations – both in terms of the ways in which the materials, devices and organisms may themselves be transformed, and with respect to how these transformed materials, devices and organisms interact with their wider environments. The 'ideology of nano-atomic precision' refers to the tendency within scientific and popular discourses to exaggerate the level of precision of understanding and control of nature at the nano-level, as well as the tendency to conceal or not recognise the new forms of uncertainty and unpredictability associated with this level of engagement with nature (Scrinis, 2006b).[2]

Nanoparticles are already recognised as a potentially very serious toxic hazard to human health and the environment (Belfield, 2005). Nanoparticles in foods in particular — whether in the form of food additives or nanochemical pesticides — "raise legitimate nutritional and health concerns and safety problems" (Pusztai and Bardocz, 2006: 167). The release of nano-engineered living organisms that are capable of reproducing also potentially creates novel hazards reminiscent of the new order of risks associated with the release of genetically engineered organisms (Crook, 2001). The release of these new organisms and materials into the environment and into the food chain heralds the emergence of a new form of ecological pollution, or what can be referred to as nano-pollution (Scrinis, 2006a). There is currently limited understanding of the distance nanoparticles may travel through agricultural environments, or their likely health and environmental impacts. Nor do we understand the health impacts of exposure to nano-particles in the workplace, or the ingestion of nano-particles in food. These potential hazards are exacerbated by a lack of regulation and labelling requirements (Institute for Food and Agricultural Standards, 2007), and by the current limits in public understanding, and public education, related to nanotechnology (Stilgoe, 2007).

Forms of Production and Consumption

In terms of the material practices and forms of production and consumption, nanotechnology is likely to be used to facilitate both the expansion and fine-tuning of large-scale, standardised, mechanised, integrated and capital-intensive production, distribution and retailing systems, as well as to meet the growing demand for more differentiated, tailored, quality or value-added end products (Friends of the Earth, 2008 forthcoming).

In the agricultural sector, for example, nanotechnology is being used to enhance the efficiency and productivity of large-scale chemical-industrial and genetic-corporate farming systems. The 'efficiencies' and productivity gains of remote sensor farming, for example, may only be realised on large-sized, capital-intensive farms. In the food processing sector, nanotechnology provides new techniques and materials for the cost-effective mass-production of cheap and standardised food products. Nano-packaging will meet the increasing demand for the long distance transportation and long shelf-life of fresh foods and ready-to-eat meals (ETC Group, 2004; Friends of the Earth, 2008 forthcoming).

Within the context of these highly uniform industrial production systems and their standardised products, nanotechnology also introduces new possibilities for the differentiation of production systems and final food products.[3] This differentiation includes the development of micro-managed large-scale farms that allow the differentiation of specific fields; the development of food crops with modified nutrient and functional traits; the manufacture of processed foods with a wider variety of features and functionalities; and packaging to enable the improved transportation, shelf-life and year-round availability of quality foods such as fresh foods and ready meals (Moraru, 2003). Nanotechnology will also facilitate the growing demand for the identification or identity preservation of products across the food system, for the purposes of food safety, quality control, segmented supply chain logistics, consumer data gathering, and patent surveillance (Mannino, 2007; ETC Group,

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[2] The ideology of nano-atomic precision is similar to the 'ideology of genetic precision' that has characterised the dominant discourses surrounding the introduction of genetic engineering, particularly with respect to genetically modified organisms and crops (Scrinis, 2000; 2006b).

[3] On the logic of differentiation, see Allaire and Wolf, 2004.

2004). Once again, these applications are likely to favour the larger agri-food and retailing corporations.

In terms of food consumption practices, the use of nanotechnology to manufacture processed foods with enhanced processing, health and packaging functionalities — flavour, texture, shelf-life, transportability, reduced costs and nutritional traits — will facilitate the expansion of the range, quality and quantity of processed foods, and to thereby meet the contemporary demands for both ‘health’ and ‘convenience’ (Dixon and Banwell, 2006). The new possibilities for producing so-called ‘functional foods’ with modified nutrient profiles will also accentuate the growth in demand for these foods, and further promote a nutritionally reductive approach to food and bodily health (Scrinis, 2008a forthcoming). The prospect of ‘smart’ nutrient delivery systems and ‘smart’ food packaging for pathogen detection are also distinctly novel applications, and may contribute to the transformation in our relationship to food, in the knowledge and skills of food preparation, and in ways of understanding and shaping the relationship between food and bodily health.

At the same time that nanotechnologies are likely to support the on-going expansion of the dominant or conventional agri-food sectors, it is not inconceivable that nanotechnologies might also be integrated within alternative agri-food practices and systems of production. The organic agriculture and food industries, for example, may support the application of nanotechnologies, especially those that have the potential to enhance sustainable farming practices – for example by reducing chemical and water use. At the same time, however, the organic sector is strategically positioned as a safe, healthy and environmentally friendly food alternative (Lyons, 2001). Nanotechnologies may jeopardise this reputation. The international organic community already appear wary of nanotechnology, and may well opt to exclude nanotechnologies from organic farming systems, in a similar way GMOs have been excluded (see Paull and Lyons, 2008 forthcoming).

Economic Relations

In terms of economic relations and structures, nanotechnology enables the further commodification of agri-food relations of production and consumption, and the extension of corporate concentration, control and integration of the agri-food system.

Firstly, nanotechnology will extend the processes of *techno-commodification* and techno-scientific dependency that have already penetrated deeply into relations of food production and consumption. The term ‘techno-commodification’ is here defined as where technologies directly mediate or enable the commodification of social relations, knowledge and material practices. Within the food system, the knowledge, skills and practices of farmers, processors and food consumers may be further appropriated, commodified and embedded within ‘smart’ and value-added inputs, technological packages and food products (Kloppenburg, 2004).

On the farm, this may include new techniques for integrating seeds and chemical inputs (such as chemically-triggered seeds traits); new tools for data gathering and evaluation (such as nano-sensors and other precision farming technologies for the micro-management of large-scale farms); new crop or animal traits that address emerging agronomic problems or consumer demands, and that thereby entice farmers to switch to patented seeds that are subject to ‘technology fees’ and binding contracts, as are many genetically modified crops; and the further undermining of subsistence practices, such as on-farm breeding (Friends of the Earth, 2008 forthcoming). The nanotechnological treadmill may join the existing chemical and genetic treadmills already confronting farmers, and create new forms of technological dependency, as well as financial and ecological risks for farmers (Scrinis, 2007; Goodman and Redclift, 1991; Kloppenburg, 1992). Nanotechnology also threatens to intensify the reduction and displacement of farm labour, through the ability to expand the use of mechanical and chemical technologies, or to automate other skilled tasks or decision-making practices. This process of technological innovation – and the subsequent displacement of farm labour – has been characteristic of agricultural development across many parts of the world since the early 20th century. Goodman and Redclift (1991; 102) argue that this 'treadmill' of competitive innovation was – and continues to be – supported by agricultural research and development, as well as agricultural and technology policies. This trend has the dual effect of locking farmers into the on-going purchase of technological innovations (for example seeds and agri-chemical inputs), while at the same time extending the reach and authority of corporate agri-food industries (Goodman and Redclift, 1991).

For the food processing industry, techno-commodification may take the form of new proprietary techniques for modifying the nutrient profile of foods and introducing new packaging functionalities that provide new value-adding possibilities. For consumers, the knowledge and skills for understanding and preparing tasty and healthy foods and diets may be further appropriated where this knowledge and skills are embedded within modified and value-added foods and food packaging.

To refer to a 'nano-corporate' paradigm is to both emphasise the dominance of the corporate economic form *per se* in the contemporary period, as well as the close interconnection between these respective technological and economic forms (Scrinis, 2007). There is a very strong sense in which nanotechnology — and other recent techno-scientific forms, such as genetic engineering — are *corporate technologies*, both in the sense that it is corporations that predominantly own and control these technologies and their associated patents and products, as well as in the sense that corporations are using these technologies as one of their primary strategies for restructuring and extending their control of the agri-food system (see for example Boyd, 2003). Agri-food corporations are likely to determine the types of nanotechnological techniques, materials and products that are developed and commercialised. Nano-agricultural research and development, for example, is likely to be driven by large seed, biotech and chemical corporations, and to be underpinned by extensive patenting (ETC Group, 2005b; Friends of the Earth, 2008 forthcoming).

The dominant economic paradigm of the agri-food system has itself been in transformation over the past couple of decades. It has been characterised by corporate concentration, integration and co-ordination within and across sectors of the food system; the shift from competitive to oligopolised markets characterised by 'clusters' of corporations cooperating across food sectors; the shift from public to private research and development; and the increasing use of patents (Heffernan, 2000; McMichael, 2005). However this trend towards an increasingly vertically integrated and homogenous food system has also been challenged in some respects by the emergence of competing and segmented systems of production delivering a wider variety of quality, health-focused and niche products (Wilkinson, 2002a). The increasingly powerful retail sector has seen supermarkets wrest dominant control of the agri-food system from the agribusiness and manufacturing sectors, in part through their ability to meet these diversifying and quickly evolving consumer demands (Burch and Lawrence, 2007). From what looked like a single and increasingly unified system, there has perhaps emerged what is more like a system of interacting systems, with competing interests amongst the dominant players and between divergent demands, though with supermarkets firmly in control at present.

In this context, nanotechnology — a technology which itself increasingly encounters living organisms, and each of their component parts, as complex systems (Dupuy and

Grinbaum, 2006) — is perhaps ideally placed to serve these various interests and structural dynamics. Firstly, nanotechnology is able to facilitate the intensification of corporate concentration and integration of the agri-food system within and across food sectors. The ability to further technically integrate the various inputs, applications and sectors of the agri-food system, may facilitate the further vertical integration or coordination of corporate ownership and control. The corporate control of farmers, for example, may be enhanced via the more precise control and engineering of technologies and inputs, such as patented and chemically-triggered seeds, seed-chemical packages, and farmer surveillance technologies (ETC Group, 2004; 2001). At the same time, just as the new biotechnologies have enabled alliances and convergences across industrial sectors — such as between the food and pharmaceutical industries (Sanguansri and Augustin, 2006) — the cross-industry character of the nanotech platform is also likely to facilitate such cross-industry alliances and convergences. Secondly, through the ability to modify production systems and end products to precise specifications and to facilitate the distribution and identity preservation of these differentiated products, nanotechnology also enables these production and distribution systems to quickly adapt to changing and diverse consumer demands, as well as to emerging ecological pressures and crises.

While the emergence of the new biotechnologies in recent years may have primarily tended to favour the agricultural sector over the food processing sector (Wilkinson, 2002b), the significant level of investment in research by the large food manufacturing corporations may indicate that significantly more benefits may flow to the final foods industry in this next stage of technological development, particularly due to the enhanced ability to create value-added and differentiated food products. At the same time, the dominant position of supermarkets may be further strengthened through nano-applications which deliver product differentiation, identity preservation and monitoring, and more flexible and enhanced product packaging and distribution possibilities.

Paradigm Shifts

Technological innovation has played an important role in shaping the development and characteristics of the agri-food system over the past century and more (Goodman et al., 1987). The emergence of the new biotechnologies of food production since the 1980s — such as genetic engineering, tissue culture and other cellular and genetic level techniques — have been identified as the basis of a new technological paradigm, and as framing the restructuring of contemporary agri-food systems. In the agricultural sector in particular, this has variously been referred to as a new ‘bioindustrial paradigm’ (Goodman and Wilkinson, 1990; Wilkinson, 2002b), a ‘genetic-corporate paradigm’ (Scrinis, 1995; 2007), or more generally in terms of a shift from a Green Revolution to a Gene Revolution form of agricultural production.

The nano-corporate food paradigm does not represent a major break with other recent technological or economic paradigms within the agri-food system, such as the biotech paradigm in agricultural production. In the case of agricultural biotechnologies, for example, there are strong similarities and continuities between genetic engineering and nanotechnology in regard to the types of agricultural practices, farming styles, patenting regimes, and corporate structures these technologies are being used to support and transform. Nanotechnology will in fact serve as an enabling technology for genetic and cellular technologies, as well as for the information technologies which have played an increasingly important role across food sectors for managing and coordinating production and distribution systems.

Nevertheless, nanotechnology is set to become the dominant technological form of the early twenty-first century, in the sense that it is the technological platform that will frame the further development — as well as the further integration and convergence — of these other contemporary techno-sciences. The scope of this technological platform — in terms of its range of applications and products — is also much broader than, say, genetic engineering, and the characteristics of the nano-corporate paradigm we have identified are to some extent common across agri-food sectors. The nano-corporate paradigm can be understood as consolidating — and enabling the further extension and convergence — of these existing technological and economic paradigms across the food system. In the agricultural sector, for example, the nano-corporate paradigm will effectively incorporate the genetic-corporate form of agricultural production.[4]

The characteristics of the nano-corporate paradigm are also broadly consistent with what Tim Lang and Michael Heasman (2004) have referred to as the emerging "Life Sciences Integrated paradigm". They argue that the life sciences integrated paradigm is one of two general responses that have emerged as a result of the limitations and crises confronting the dominant 'Productionist paradigm' towards the end of the twentieth century, with the other alternative response being the 'Ecologically Integrated paradigm'. Lang and Heasman emphasise the role of the new biotechnologies of food production for the development of genetically engineered crops, nutrigenomics, and functional foods. They acknowledge that the life sciences integrated paradigm in many respects "relies on a simple re-interpretation of the existing Productionist paradigm but claims to remedy a number of its limitations: from lessening environmental impacts, through improving human health from greater food production, to creating new products with enhanced, yet often contested, health benefits" (Lang and Heasman, 2004: 22). While Lang and Heasman do not refer to the new nanotechnologies, these technologies will certainly facilitate many of the applications and structural tendencies associated with the life sciences integrated paradigm that they identify.

As the new techno-sciences have come to play an increasingly important role across the agri-food system, they have in recent times also become the focus of civil society and social movement contestation. The strong opposition to genetically modified crops has arisen on the basis of a number of concerns, ranging from "the defence of peasant and small farmer interests, to bio-diversity, environment, animal welfare, ethics and consumer health issues" (Wilkinson, 2002a: 4). The range of issues raised reflects a growing recognition of the power of these new techno-sciences to not only introduce new health and ecological hazards, but also to increase the power of agri-food corporations over farmers and citizens' interests. This opposition has so far restricted the development and commercialisation of genetically modified crops, and has raised concerns about the emergence of a similar level of public resistance to nano-foods (Feffer, 2005; Renton, 2006). This has led to repeated calls for the nanotechnology and food industries to "learn the lessons" of biotechnology and GM foods (Grove-White *et al*, 2004). If a significant level of public and consumer resistance to the introduction of nano-foods does emerge, an important issue will be whether the now dominant retail sector will take a position of responding to consumer concerns — as supermarket chains in some countries have to GM foods, thus pitting themselves against the interests of corporations at the other end of the food chain — or whether the broad scope of nano-food applications, and supermarkets' own adoption of nano-applications, compromises their ability to respond in similar ways.

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[4] A way of categorising agricultural paradigms with reference to their dominant technological and economic forms respectively, is in terms of a progressive shift from organic-subsistence, to chemical-industrial, to genetic-corporate and nano-corporate modes of agricultural production (Scrinis, 2007; 1995).

As we are still in the relatively early stages of research and commercialisation of nanotechnology, there is considerable potential for civil society groups, workers' unions, farmer and producer organizations, environmental and consumer groups, to challenge and shape the development and implementation of this technology, and to thereby support alternative applications, regulatory regimes, and techno-economic paradigms of development.

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